Marginal Discrepancy of Screw-Retained and Cemented Metal-Ceramic Crowns on Implant Abutments

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This in vitro study quantified the marginal discrepancy of the implant-to-prosthetic-crown interface on nonsubmerged dental implants restored with either a cemented or a screw-retained approach. Metal-ceramic crowns were fabricated for 20 ITI 4.1 × 10 mm solid-screw titanium implants. Ten implants received octa abutments and screw-retained crowns fabricated on premachined gold cylinders. The remaining 10 implants were restored with 5.5-mm solid abutments and metal-ceramic crowns cemented alternately with a glass-ionomer or a zinc phosphate luting agent. Inspection of the implant-crown interface was conducted using light microscopy under ×50 magnification at selected stages in the process of crown fabrication. Statistical analysis revealed a significant difference ($P <$ .001) in the mean marginal fit between screw-retained (8.5 ± 5.7 μm) and luted implant-supported crowns. This difference was observed both before (54.4 ± 18.1 μm) and after cementation with glass-ionomer (57.4 ± 20.2 μm) or zinc phosphate (67.4 ± 15.9 μm).
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Key words: cement, dental implant, fixed prostheses, marginal discrepancy, screw-retained

The restoration of missing teeth with a functional and esthetic replacement that also maintains the health of existing oral structures is the treatment goal of clinicians and patients alike. The use of endosseous dental implants to achieve this objective has helped overcome many of the limitations encountered with conventional fixed and removable prostheses. The long-term success of osseointegrated root-form dental implants for oral rehabilitation is predicated on predictable integration with both osseous and gingival tissues.[1–7]

Only recently have the importance of peri-implant gingival structures and their role in the overall longevity of implant treatment received greater attention. The implant relationship with both hard and soft tissues should be a stable and long-lasting union that is biologically sound.

Many studies have documented the success rates of implant treatment for a nonsubmerged approach[8–10] and for single-tooth replacements.[11–17] Yet these well-publicized triumphs have overshadowed certain problems that still exist. Among such difficulties are screw loosening,[18–21] component breakage,[22] and soft tissue complications.[7,9,23] These remain a significant concern for practitioners worldwide.

Within the last few years, implant component systems have been introduced that allow prosthetic crowns to be cemented directly to the implant abutment. The rapid rise in the popularity of cementable implant prostheses has been attributed to several factors. They can be less costly and utilize fewer prosthetic components. A cemented implant crown is similar, in some ways, to fixed prosthodontic treatment on natural teeth and is therefore within the comfort level of a greater number of

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general practitioners. The cemented concept eliminates the need for a prosthetic screw and its occlusal screw access channel through the restoration, thereby improving esthetics, optimizing occlusal loading, and also limiting the incidence of loose screws and associated maintenance.[24]

This purportedly simple and inexpensive mechanism of implant restoration is not without its liabilities, however. The margins of implant-supported prostheses, especially in highly esthetic areas, are often located further subgingivally than those of tooth-supported metal-ceramic restorations. This compromise often results from the need to develop natural crown contours and proper emergence profiles from the top of the implant surface. Prosthodontic procedures such as impression making and fabrication of provisional restorations can be adversely affected by the deep subgingival placement of the proposed abutment-restoration interface.[25] Agar et al described the effects on titanium abutments during cement removal of luted restorations with subgingival margins.[26] In his study, experienced implant clinicians left a surprising amount of residual cement behind and created a significant degree of surface roughness in the process of debridement when using an explorer. While this investigation was conducted on a model that simulated a maximal subgingival margin depth of 3 mm, the clinical situation presents additional challenges. The task of removing excess set cement can be quite arduous, almost always necessitates local anesthesia, and most likely can be completed effectively only via a surgical flap procedure. The long-term effects on soft tissue health of a marginal discrepancy at this interface are only recently being appreciated.[27]

Previous studies of cemented implant crowns have evaluated the marginal discrepancy of all-ceramic restorations on CeraOne abutments using zinc phosphate cement.[28] These findings indicate that the mean marginal discrepancy of cemented crowns was less than optimal (168.8 ± 23 μm). Using a machined gold coping for their measurements, Clayton et al reported the mean marginal opening of CeraOne abutments at the restoration interface as 62 μm.[29] Earlier work by numerous investigators has sought to determine the clinically acceptable limits of marginal gap formation on natural tooth abutments. Brockhurst et al proposed a requirement that cast margins should fit with a deficiency of less than 25 μm.[30] In a laboratory setting, the absolute marginal discrepancy was found to be 36 ± 24.1 μm for electroformed crowns and 64 ± 32.7 μm for conventional metal-ceramic crowns.[31] Others concluded that subgingival margins with openings as large as 104 μm[32] and 119 μm[33] were clinically undetectable to experienced practitioners. Variability among operators evaluating the fit of dental castings has been demonstrated.[32–35] In vitro investigations suggest that marginal discrepancies in the range of 120 μm may be clinically successful.[36,37] Yet clinical success as determined by a lack of recurrent caries is not the principal criterion applied to implant-supported restorations.

Periodontal considerations with respect to marginal infidelity on conventional fixed prosthodontic units are widely known. The adverse sequelae of defective subgingival margins on periodontal health have been reported.[38,39] Access to these areas for routine maintenance and plaque removal is difficult at best. Overhanging restoration margins that facilitate plaque accumulation are directly implicated in the progression of gingival inflammation, both chronic and acute, and as a contributing iatrogenic etiology in periodontal disease.[40–42] Even the most technically superior margin placed deeply within the tissue is a potential source of periodontal inflammation and tissue breakdown.[43,44] Data from more recent work has suggested that a biologic width exists around non-submerged dental implants, similar to that found around teeth.[45] It may be surmised that this biologic entity is subject to the same physiologic forces as natural teeth, and the long-term peri-implant health of an implant restoration may be dictated by similar principles of marginal integrity.

The goal of this in vitro study was to assess the magnitude of marginal discrepancy at the implant-to-prosthetic-crown interface of ITI dental implants restored with screw-retained and cemented prostheses.

Materials and Methods

Specimen Preparation. Twenty ITI 4.1×10 mm solid-screw dental implants (Straumann USA, Waltham, MA) were used for this study. The implants were delivered from a single lot of commercially available stock and were randomly divided into 2 equal groups of 10 specimens each. The first group was selected to receive a cement-retained restoration and the second group a screw-retained restoration.

For group 1, individual 5.5-mm solid abutments were connected to the 10 implants and tightened with a torque wrench to 35 Ncm. For group 2, an octa abutment (Straumann USA) was connected to each of the remaining 10 implants, using the same torque wrench, to 35 Ncm. Metal-ceramic crowns were then fabricated for both groups according to standard laboratory protocol. Special caution was

taken to avoid damaging the intaglio surface of the premachined gold copings. The solid abutment castings were then fit back to the master dies under 10× magnification through selective grinding. They were then air-abraded with 50-μm aluminum oxide particles at 50 psi from a distance of 3 cm for 10 seconds. Porcelain application was completed in the following 5 oven cycles: oxidation 1038°C, opaque 940°C, first body 930°C, second body 945°C, and glaze 960°C (Vita-Omega, Vident, Brea, CA). The completed crowns were returned to their respective master dies for marginal finishing and polishing with medium- and fine-grit diamond-impregnated rubber wheels on a low-speed laboratory handpiece.

Final prosthesis delivery was completed for both groups on their original matched implant. The cemented group specimens were divided equally to test 2 separate luting agents. Five of the specimens in group 1 (1, 3, 5, 7, 9) were first cemented to the implant-abutment assembly using a glass-ionomer luting agent (Ketac-Cem Applicap, ESPE America, Norristown, PA). The remaining 5 (2, 4, 6, 8, 10) samples were cemented with zinc phosphate luting agent (Modern Tenacin, Caulk Dentsply, Milford, DE). The cements were mixed according to manufacturers' specifications and painted onto the internal surface of the casting with a disposable brush. The cemented crowns were seated with finger pressure and then a static vertical load of 10 kg was applied for 10 minutes. Excess set cement was removed from the margins with a plastic implant curette. Specimens were stored at 37°C in 100% humidity for 24 hours. The implant bodies were secured in a universal testing instrument (Instron 1011, Canton, MA) with a calibrated 100-pound load cell. Samples were loaded to cement failure at a crosshead speed of 1 mm/min, and separation forces were recorded.

Following data collection for the first luting agent, the crowns were removed from their respective implant-abutment assemblies. The intaglio surfaces of the crowns were cleaned and prepared with careful air-abrasion as previously described. The crowns were then recemented using the second luting agent. In the screw-retained group, specimens were delivered to their respective implant-abutment assemblies and affixed with a titanium occlusal screw (4 mm SCS, Straumann USA) at a measured torque of 15 Ncm.

Data Collection. Inspection of the marginal discrepancy at the implant-crown interface was conducted under 50× magnification using a stereomicroscope (Zeiss Stereomicroscope Model SR, Carl Zeiss, Thornwood, NY). The principal investigator collected the measurements 3 times each at 4 marked locations (0 degrees, 90 degrees, 180 degrees, 270 degrees) around the implant circumference (Fig 1). Data were recorded to the nearest 0.001 mm. It was necessary to measure the marginal discrepancy from the inferior border of the implant shoulder bevel so as to include overextended castings that would otherwise obscure the true finish line. The actual marginal discrepancy values were then calculated by subtracting the mean height of the shoulder bevel (80.1 ± 6.2 μm for the screw-retained specimens and 81.2 ± 3.8 μm for the cemented specimens) from the quantities measured using the reference point (Fig 2).

Measurements were made for both groups at selected stages in the crown fabrication process. The first marginal discrepancy measurements were made of the gold cylinders as received new from the manufacturer prior to fabrication of screw-retained crowns (Fig 3a). Measurements were then made after casting the metal-coping sub-structures for both the screw-retained (Fig 3b) and cemented (Fig 4a) groups. Measurements were made again following porcelain application and marginal polishing of completed restorations for both groups of samples (Figs 3c, 4b). The final measurements were made after luting the cement-retained crowns with a glass-ionomer (Fig 4c) and a zinc phosphate agent (Fig 4d) in an alternating fashion.

Statistical Analyses. SPSS statistical software for Windows (release 7.5, SPSS, Chicago, IL) was used for all statistical procedures. Marginal discrepancy values were compared for cemented and screw-retained metal-ceramic crowns using an independent-sample t test at a significance level of $P \le .05$. A paired-sample t test was used to compare marginal discrepancy with respect to cement type.

Results

The results of the mean marginal discrepancy portion of the study are shown in Table 1. The actual marginal discrepancy values were obtained by computing the difference between the directly measured marginal discrepancy and the height of the implant shoulder bevel that provided the measurement reference point. The smallest measured mean marginal discrepancy was found for the screw-retained machined gold cylinders prior to casting (2.6 ± 5.7 μm). The remaining 2 screw-retained groups, the cast gold cylinders (6.0 ± 6.5 μm) and the finished metal-ceramic crown restoration (8.8 ± 5.7 μm), followed closely behind. For the cement-retained specimens, the initial cast gold alloy coping (32.1 ± 32.5 μm) proved to have the
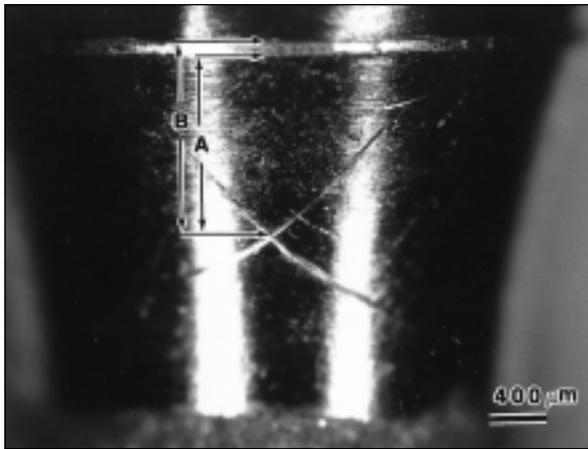
Fig 1 ITI implant polished collar. A = reference point to apical junction of bevel; B = reference point to margin of metal-ceramic restoration (original magnification ×25.6).
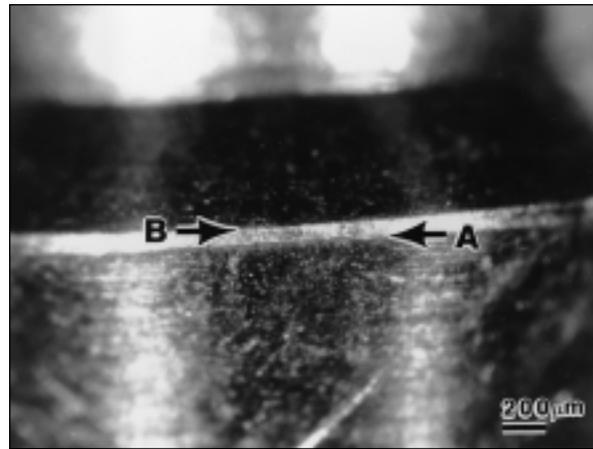

Fig 2 ITI implant shoulder bevel. A = apical junction of bevel and implant polished collar; B = coronal aspect of bevel indicating finish line of restoration (original magnification ×40).

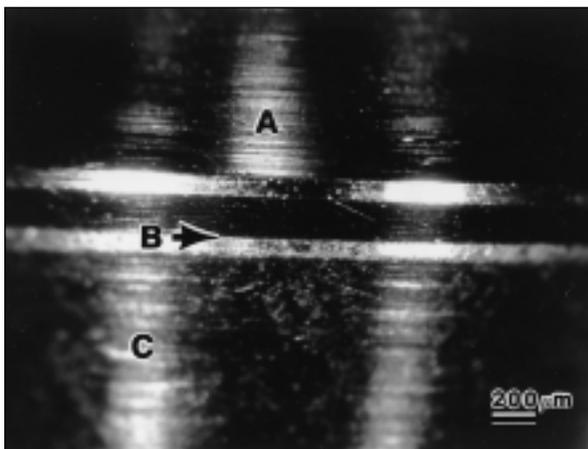**Fig 3a** New machined gold cylinder attached to implant. A = gold cylinder; B = implant-restoration junction; C = implant body (original magnification ×40).
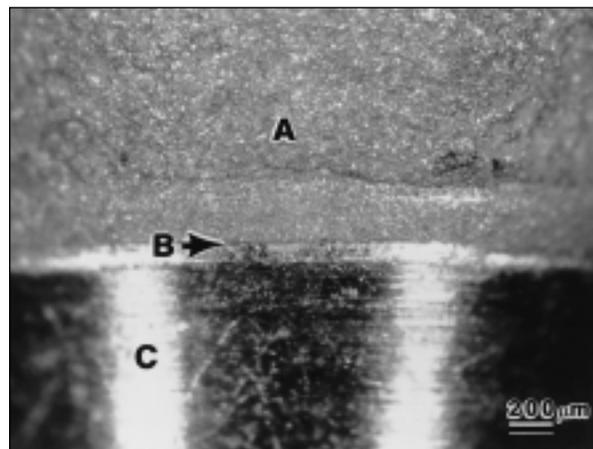

Fig 3b Cast metal-ceramic alloy on machined gold cylinder. A = cast coping on gold cylinder; B = implant-restoration junction; C = implant body (original magnification ×40).
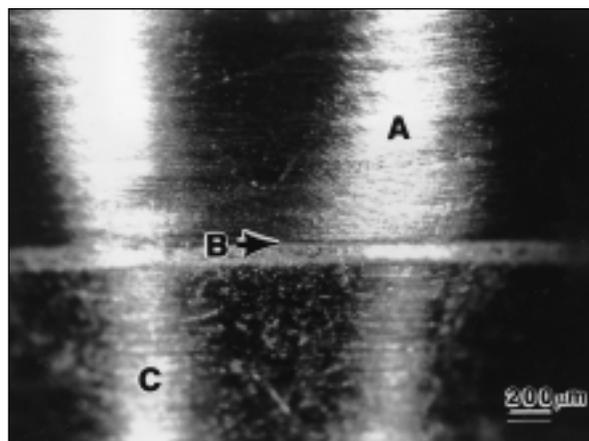

Fig 3c Finished metal-ceramic crown on machined gold cylinder. A = metal margin of polished crown; B = implant-restoration junction; C = implant body (original magnification ×40).
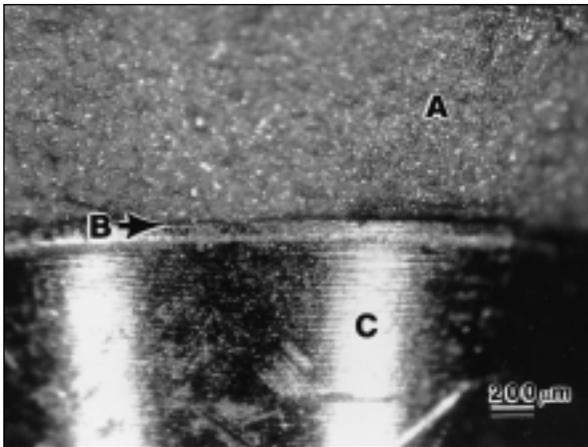
Fig 4a Cast metal-ceramic alloy coping on implant. A = cast coping; B = implant-restoration junction; C = implant body (original magnification ×40).
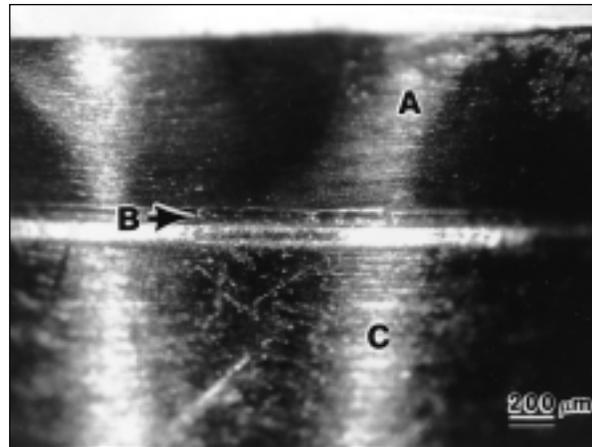

Fig 4b Finished metal-ceramic crown prior to cementation. A = metal margin of polished crown; B = implant-restoration junction; C = implant body (original magnification ×40).
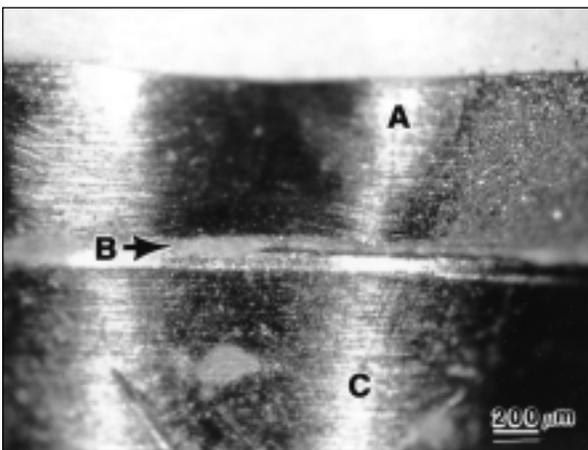

Fig 4c Metal-ceramic crown cemented using glass-ionomer luting agent. A = metal margin of polished crown; B = implant-restoration junction; C = implant body (original magnification ×40).
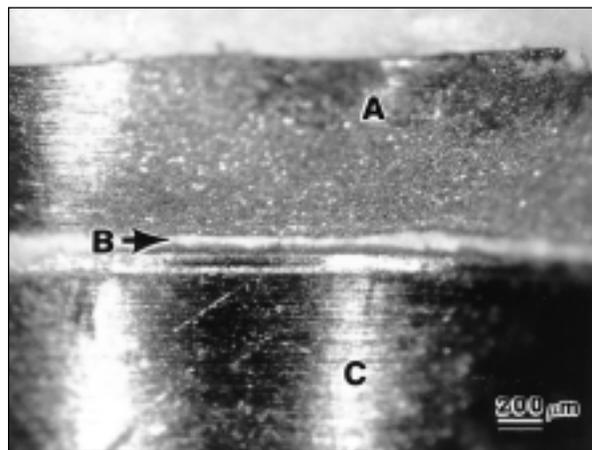

Fig 4d Metal-ceramic crown cemented using zinc phosphate luting agent. A = metal margin of polished crown; B = implant-restoration junction; C = implant body (original magnification ×40).

Table 1 Mean Marginal Discrepancy of Screw-Retained and Cement-Retained Crowns

Specimen group (n=10)	Distance from reference point ± SD (µm)	True marginal discrepancy ± SD (µm)
Screw-retained		
New gold cylinder	82.7 ± 5.2	2.6 ± 5.7
Cast gold cylinder	86.1 ± 6.5	6.0 ± 6.5
Finished porcelain	88.9 ± 5.1	8.8 ± 5.7
Cement-retained		
Cast gold coping	112.2 ± 33.5	32.1 ± 32.5
Finished porcelain	134.5 ± 20.1	54.4 ± 18.1
Glass-ionomer cemented	137.5 ± 22.0	57.4 ± 20.2
Zinc phosphate cemented	147.3 ± 17.3	67.4 ± 15.9

Implant shoulder bevel = 80.1 ± 6.2 µm for screw-retained, 81.2 ± 3.8 µm for cement-retained.

best fit to the implant-abutment assembly. Once the metal-ceramic restoration was completed, but prior to cementation, the marginal discrepancy increased (54.4 ± 18.1 µm). After cementing the specimens with a glass-ionomer luting agent, a slight increase in marginal discrepancy was noted (57.4 ± 20.2 µm). The largest marginal discrepancy was evident for specimens cemented with zinc phosphate (67.4 ± 15.9 µm). An independent-sample *t* test revealed a significant difference in the mean marginal discrepancy of screw-retained and cemented metal-ceramic crowns (*P* < .001), even when controlling for the difference encountered at the time of casting (*P* = .037). Additionally, a direct comparison of cements using a paired *t* test showed a significant difference between the marginal discrepancy of crowns cemented with glass-ionomer and zinc phosphate (*P* = .027).

Discussion

Several investigators have measured the marginal discrepancy of cemented implant restorations. Sutherland et al found the marginal discrepancy of cemented all-ceramic crowns to be rather large (168.8 ± 23 µm).[28] Another study of the CeraOne abutment system using a cementable machined gold coping found mean marginal openings ranging from 23.667 ± 6.802 µm with a composite resin luting agent to 62.167 ± 13.348 µm with zinc phosphate cement.[29] In the same study it was also noted that glass-ionomer use resulted in a marginal gap of 29.667 ± 10.289 µm.

The terminology used to describe the marginal fit of dental restorations is not uniform throughout the literature. The present study measured the vertical marginal discrepancy, which was described by Holmes et al as the "vertical marginal misfit measured parallel to the path of draw of the casting."[46] Measurement data were obtained by positioning the specimens under the microscope so that the marginal area of the implant-restoration junction was viewed from a directly perpendicular perspective. Other investigators have also used this methodology to easily and accurately report on this major contributor to marginal misfit.[28,29] Also, it allows measurement of the marginal discrepancy in a nondestructive format that allows multiple readings on specimens throughout the prosthetic crown fabrication process and with various different luting agents.

The design of the ITI implant includes a bevel (80.1 ± 6.2 µm) at the junction between the implant's polished collar and 45-degree shoulder (Fig 2). The coronal aspect of this bevel, where the implant shoulder terminates, is the external finish line of the implant-crown interface. For this study, measurements were made from the apical extent of this bevel, 80 µm below the actual implant "margin," to facilitate measurement of overcontoured crown margins that would otherwise obscure the finish line. The distance between an orientation mark on the polished collar portion of the implant shoulder and the apical bevel reference was recorded and subtracted from the measured distance between the orientation mark and the crown margin (Fig 1). The resulting difference was the measured "marginal discrepancy." The true marginal discrepancy is more accurately arrived at indirectly, by subtracting this 80-µm height from the measured discrepancy value. Thus, the mean marginal discrepancy for the completed screw-retained metal-ceramic crown is more accurately described as 8.8 ± 5.7 µm. For cemented restorations, the marginal misfit using glass-ionomer is 57.4 ± 20.2 µm and 67.4 ± 15.9 µm for zinc phosphate. These values clearly demonstrate the superior fit of screw-retained restorations. Also, the marginal discrepancies of cemented restorations under the conditions of this study are within clinically acceptable limits.[31–37]

The machined internal patrix of the prefabricated gold coping fits intimately over the implant-abutment matrix. The marginal discrepancy of these copings as received new from the manufacturer (2.6 ± 5.7 µm) served as a control (Fig 3a). No significant difference in the mean marginal gap was found after casting a high-noble metal-ceramic alloy to the copings (6.0 ± 6.5 µm, Fig 3b). The comparative misfit of cast metal copings for cemented crown fabrication (32.1 ± 32.5 µm) demonstrated that a significant difference existed early in the process (Fig 4a).

The laboratory process of metal-ceramic crown fabrication increased marginal discrepancy by 6 µm for screw-retained prostheses and by 22 µm for cemented prostheses (Table 1). After porcelain application and final polishing, the marginal discrepancy of completed metal-ceramic crowns for a screw-retained approach was 8.8 ± 5.7 µm (Fig 3c). Prior to luting, completed cement-retained crowns exhibited a marginal gap of 54.4 ± 18.1 µm (Fig 4b). Although distortion of the metal framework during porcelain firing can contribute partly to an increase in marginal misfit, the majority of the discrepancy is likely the result of finishing and polishing of the marginal area. Even with careful attention while using magnification, the dental technician is likely to remove even a small amount of material from the restoration's margin in an effort to achieve a highly polished surface. Metzler and Chandler found that the best marginal

closure was obtained on gold castings in vivo by slightly overwaxing the margin and then finishing those accessible margins intraorally.[47] This practice is not possible on implant-supported restorations, but it highlights the importance of attention to laboratory detail. Also, a major difference noted between the cemented and screw-retained groups was the material from which the master die was fabricated. For the cemented prostheses, the margin is waxed and finished to a plastic shoulder analog provided by the manufacturer. Although this is a fairly durable material, the shoulder analog, like a stone die, can be readily abraded by imprudent use of finishing stones or rubber wheels. In contrast, the screw-retained crowns are constructed on metal octa analogs, which are more resistant to overzealous finishing procedures. This difference could have accounted in part for the greater discrepancy found in cemented restorations.

Another factor to consider is the effect of cementation on the creation of additional marginal misfit. Following cementation of implant crowns, the marginal discrepancy was 57.4 ± 20.2 µm when glass-ionomer was used (Fig 4c) and 67.4 ± 15.9 µm when zinc phosphate was used (Fig 4d). Previous studies have investigated various attempts to improve the marginal adaptation of cemented restorations.[48–52] Fusayama and others recommended the use of die-spacer to limit marginal gap formation.[53–59] Axial grooves were shown to assist in the flow of excess cement from within the casting and minimize the filtration phenomenon seen with zinc phosphate.[60,61] While dynamic loading and vent formation have been proven to minimize seating discrepancies, neither technique is commonly used because of obvious drawbacks.[62,63] Cement was evenly applied with a small brush to the internal surface of the crowns to minimize the effect of cement volume on crown seating.[64]

Even when controlling for the disparity found between cemented and screw-retained restorations as a result of the casting process, a significant difference still existed between the 2 groups. While marginal finishing played a role, as discussed previously, the effect of cement film thickness on seating is not to be overlooked. ANSI/ADA specifications for zinc phosphate and glass-ionomer cements require a maximum film thickness of 25 µm for both materials.[65] The luting agents performed well within this range, as the addition of glass-ionomer only increased mean marginal discrepancy by 3 µm. Zinc phosphate application also conformed by adding approximately 13 µm to the overall misfit, but this difference between cements was large enough to be found significant.

In an effort to evaluate the marginal adaptation of crowns luted with different agents, it became necessary to remove previously cemented crowns from their implant-abutment complex. An argument can be made that changes in casting fit could be introduced by cementing, pulling, cleaning, air-abrading, and recementing each specimen. While acknowledging a potential source of error, however small, this nondestructive method of data collection allows observation throughout the different stages of fabrication. This format also permits a paired approach to data analysis that negates the error encountered related to interspecimen variability.

The goal of this project was to assess the magnitude of marginal discrepancy of a completed metal-ceramic crown as it would be found in the clinical situation. It could be further concluded that these findings represent a best-case scenario, as the seating of the finished prosthesis was not inhibited by the soft tissues often present in intimate approximation with implants in situ (Fig 5). Clinical experience dictates that as the depth of the implant-restoration interface increases, the likelihood of trapping gingival tissues and incomplete seating of the prosthesis increases greatly. Cochran et al found the formation of a biologic width around loaded, nonsubmerged dental implants in an animal model.[45] In their study, histologic analysis of implants restored with screw-retained gold crowns revealed a minimal number of inflammatory cells within the connective tissue and soft tissue morphology that appeared normal. Work by Jansen et al confirmed that microbial leakage and colonization occurs at the marginal gap created by the implant-abutment interface and could be responsible for soft tissue inflammation.[66] Numerous investigators have reported the effects of instrumentation and oral hygiene on the surface characteristics of transmucosal titanium abutments.[67–69] Metal curettes and ultrasonic scalers have been shown to increase the surface roughness of titanium components, which in turn can promote microbial plaque adherence.[70–72] Also, the bacterial composition of deep peri-implant bone pockets has been reported to be consistent with that of advanced periodontal lesions, in which certain pathogens are found in higher proportions.[23] These findings highlight the need for optimal smoothness of subgingival implant surfaces and meticulous hygiene to ensure the health of peri-implant tissues.

Certain indisputable clinical correlations exist between teeth and titanium implants. Extensive data confirming the success and longevity of tooth-supported prostheses, as well as reasons for and modes of failure, should not be ignored in the case
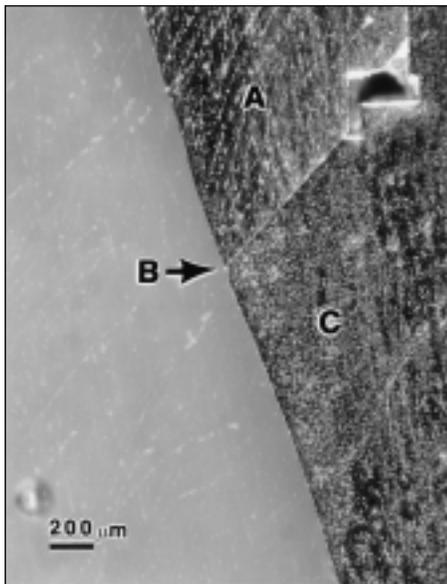
Fig 5a Transverse section of screw-retained specimen. A = metal-ceramic crown; B = implant-restoration junction; C = implant body (original magnification ×40).
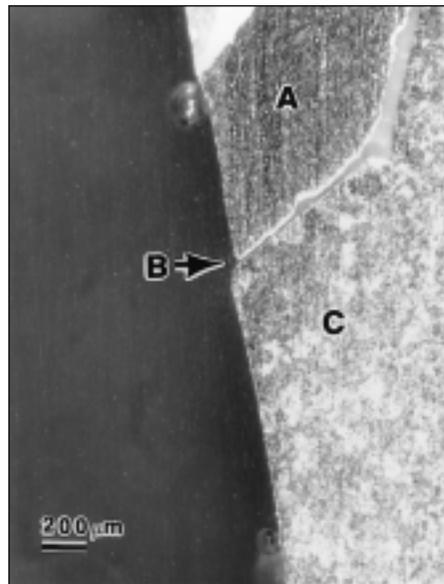

Fig 5b Transverse section of cement-retained specimen. A = metal-ceramic crown; B = implant-restoration junction; C = implant body (original magnification ×40).

of dental implants.[40,73] While implants may not be subject to recurrent caries or dentinal hypersensitivity, poorly fitted restorations may have long-term implications that affect the total "biointegration" of the implant-restoration complex within the hard and soft tissues. The findings of this study suggest that a smaller marginal discrepancy can be expected for screw-retained metal crowns on non-submerged implants. Future efforts should be directed at an in vivo investigation of this marginal discrepancy and its clinical relevance in relation to long-term peri-implant health.

Conclusions

Under the conditions of this in vitro investigation it can be concluded that:

1. The mean marginal discrepancy of screw-retained metal-ceramic crowns on implant abutments is significantly smaller than that of cemented metal-ceramic crowns.
2. The mean marginal discrepancy of metal-ceramic crowns cemented on implant abutments with glass-ionomer is significantly smaller than those cemented with zinc phosphate.

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